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(54) **METHOD AND APPARATUS FOR MACHINING HOLES IN CRANKSHAFTS**

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(52) **U.S. Cl.** .... **483/1**; 29/26 A; 408/1; 408/46; 408/50; 408/72 R; 409/164; 409/189; 409/224; 483/16; 483/30

(58) **Field of Search** .... 483/1, 14, 15, 483/17–19, 30, 36, 58; 408/43, 44, 46, 50, 72 R; 29/26 A, 27 R, 888.08; 409/164–166, 168, 197, 198, 221, 224, 227; 219/69.11; 82/106, 124

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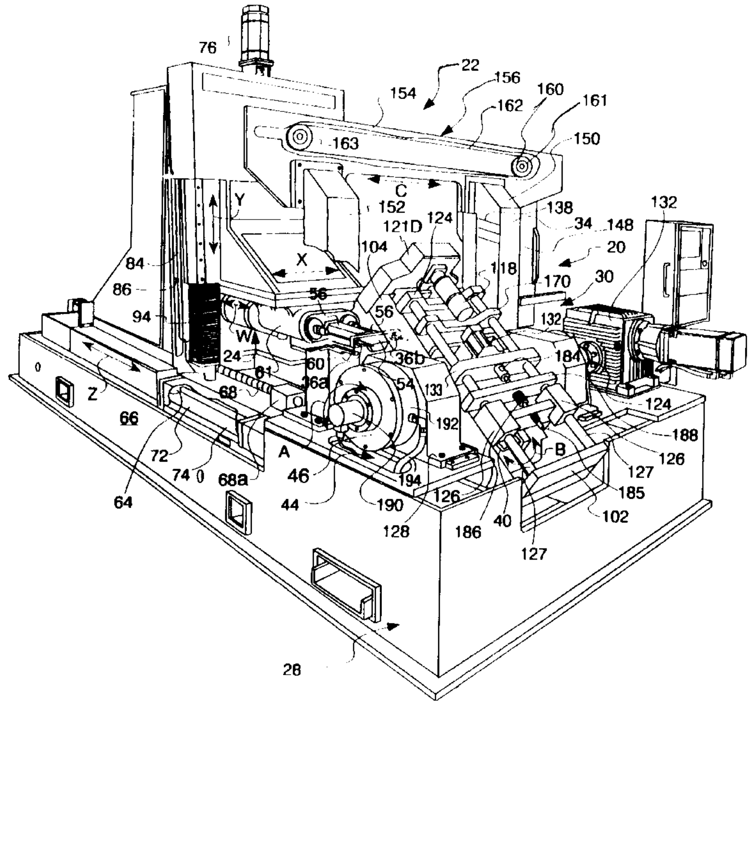
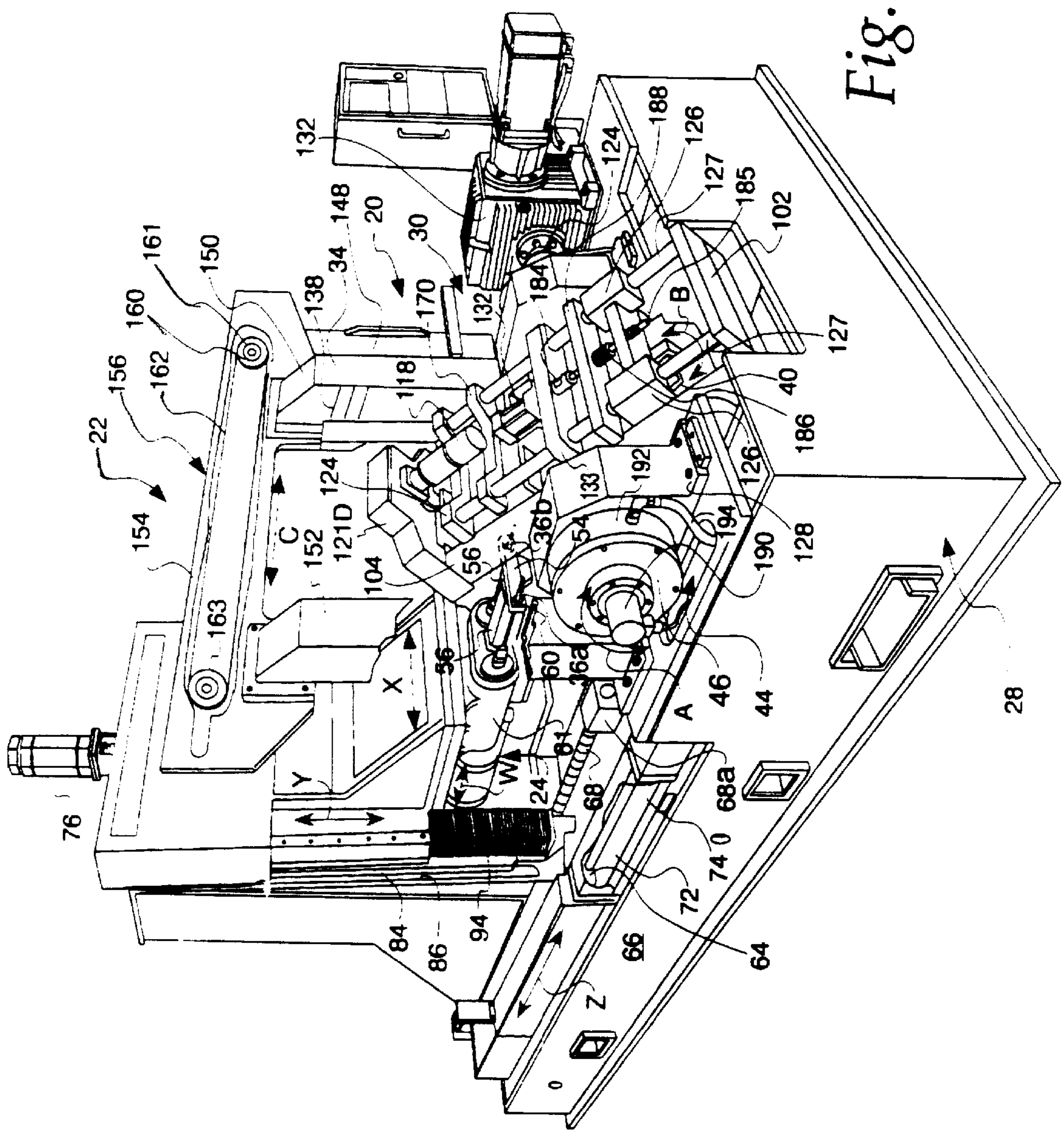
(57) **ABSTRACT**

A crankshaft is mounted in a fixture which rotates the crankshaft about its longitudinal axis and which tilts the cranksahft about a horizontal axis to allow matching of holes such as oil holes at various rotational positions and at various tilt angles to the longitudinal axis. Preferably, a cutting tool moves along a horizontal plunging axis Z to machine the depth of the hole and moves along a horizontal X axis to machine holes on or offset from the longitudinal axis. The cutting tool may also be shifted vertically along a Y-axis. Preferably, a pair of crankshafts are mounted side-by-side in the fixture to machine two crankshafts simultaneously. The fixture is mounted for tilting by trunnions. The pair of crankshafts are spun about the longitudinal axes by a motor carried on the tiltable fixture. An automatic tool changer and loading apparatus store cutting tools and associated guide bushings for the cutting tools.

40 Claims, 8 Drawing Sheets

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36b
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A
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Fig. 1

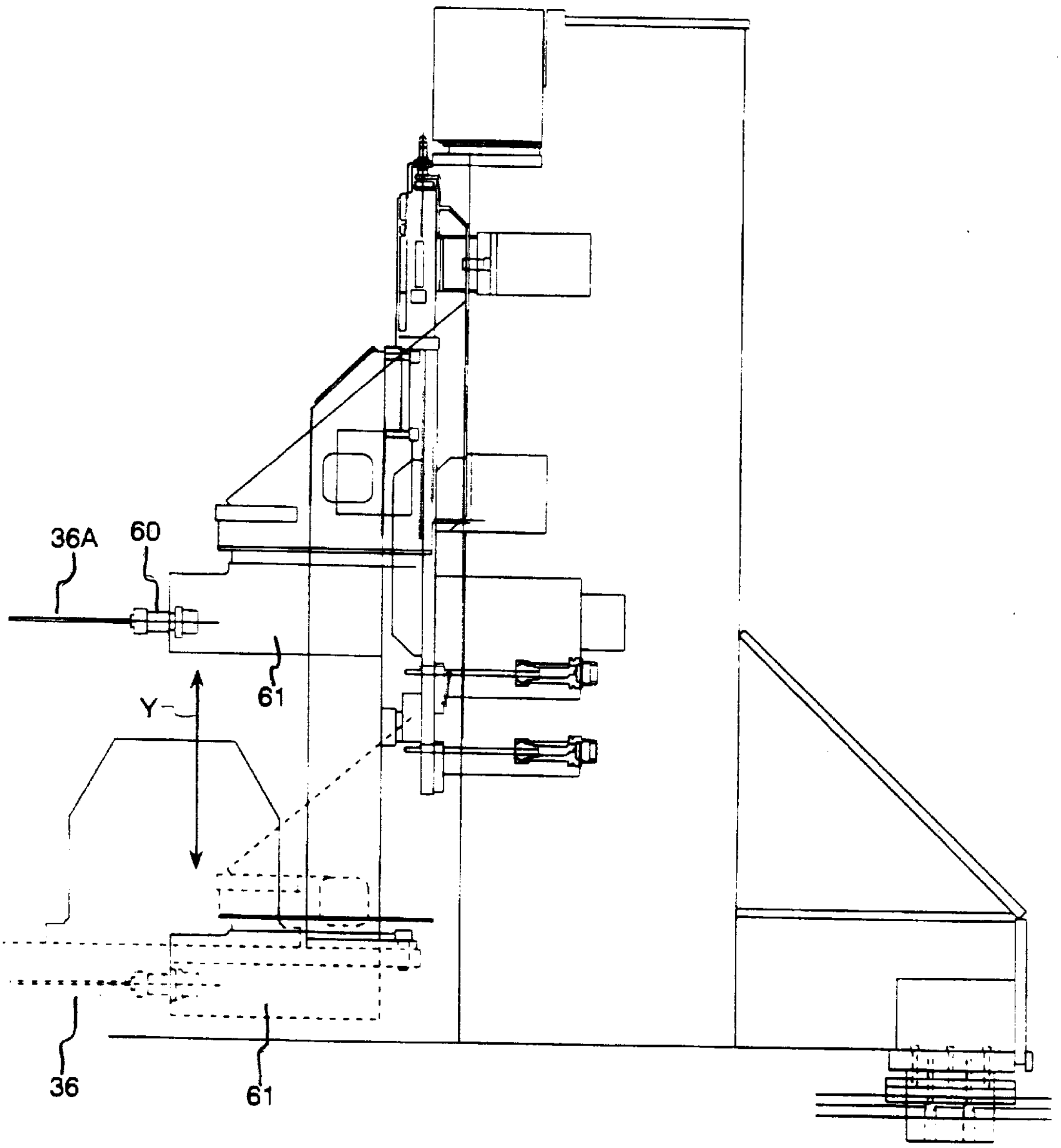


Fig. 2

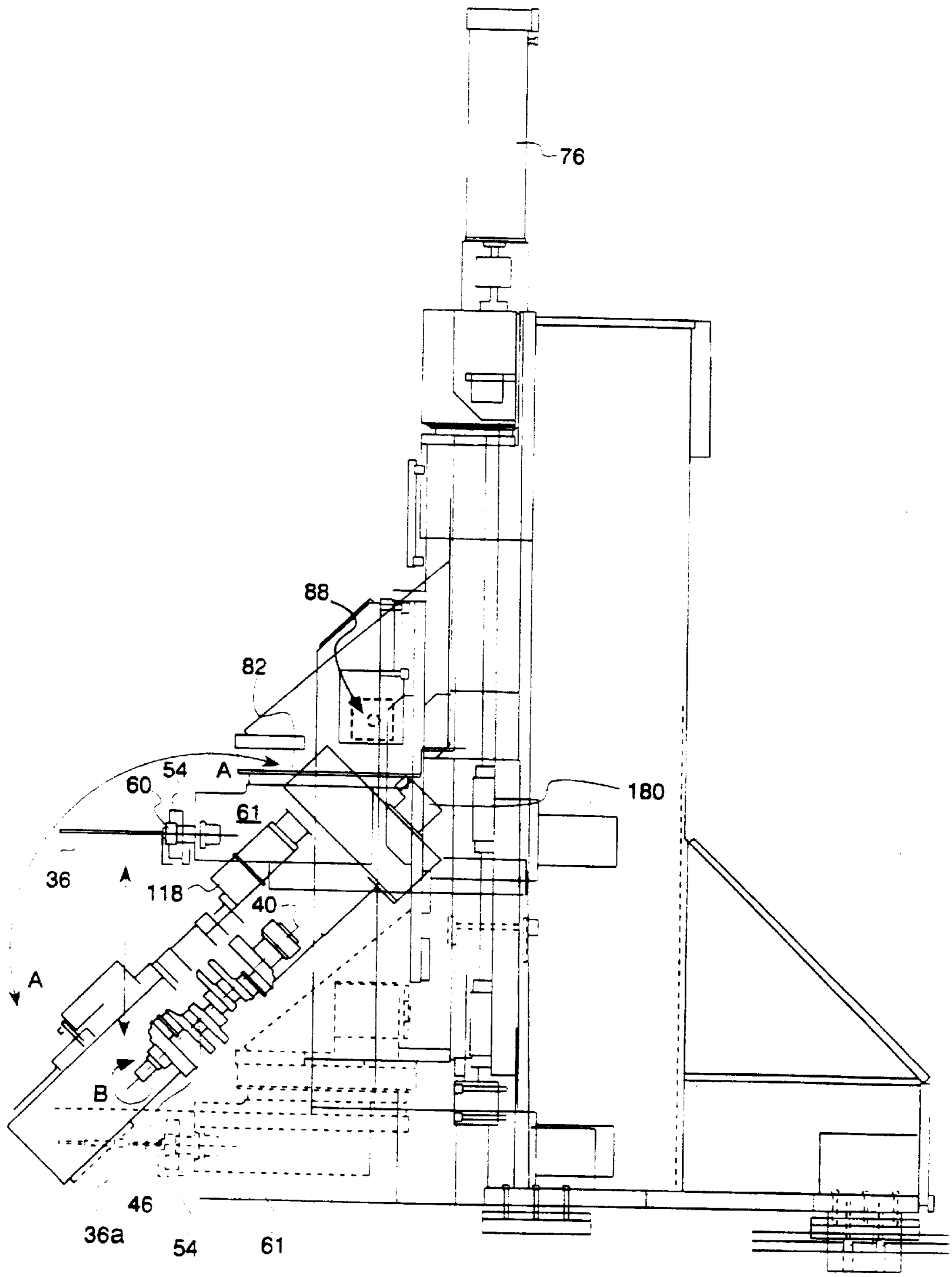
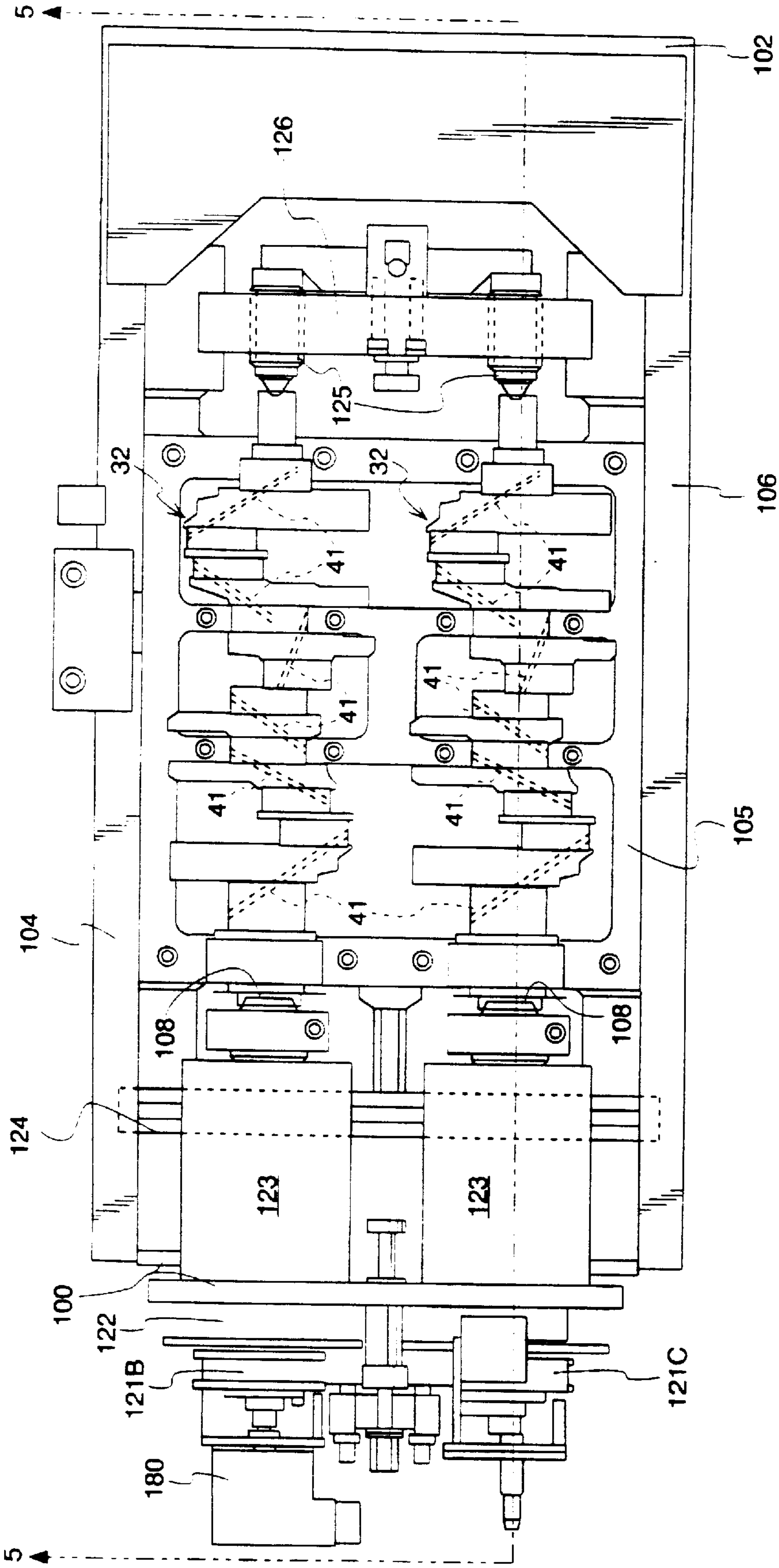


Fig. 3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32
106
41
41
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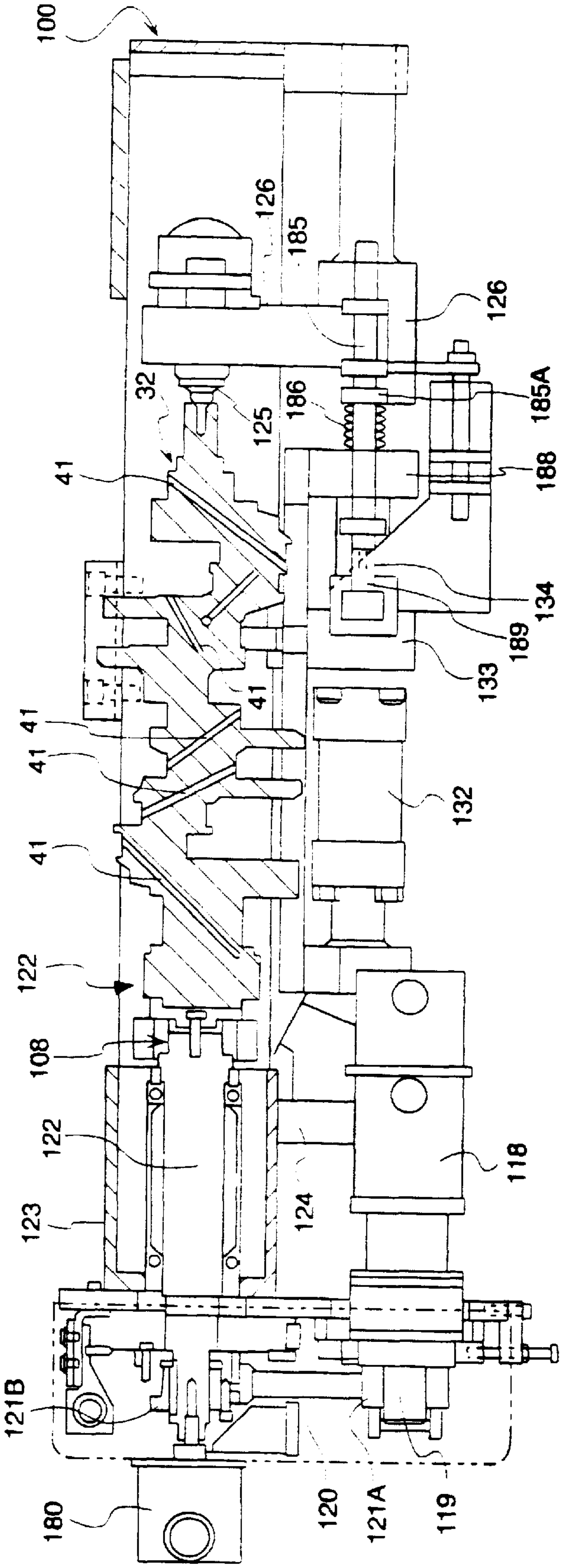
100
122
121B
121C
180
5

Fig. 4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188
134
189
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118
124
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121B
180
120
121A
119

Fig. 5

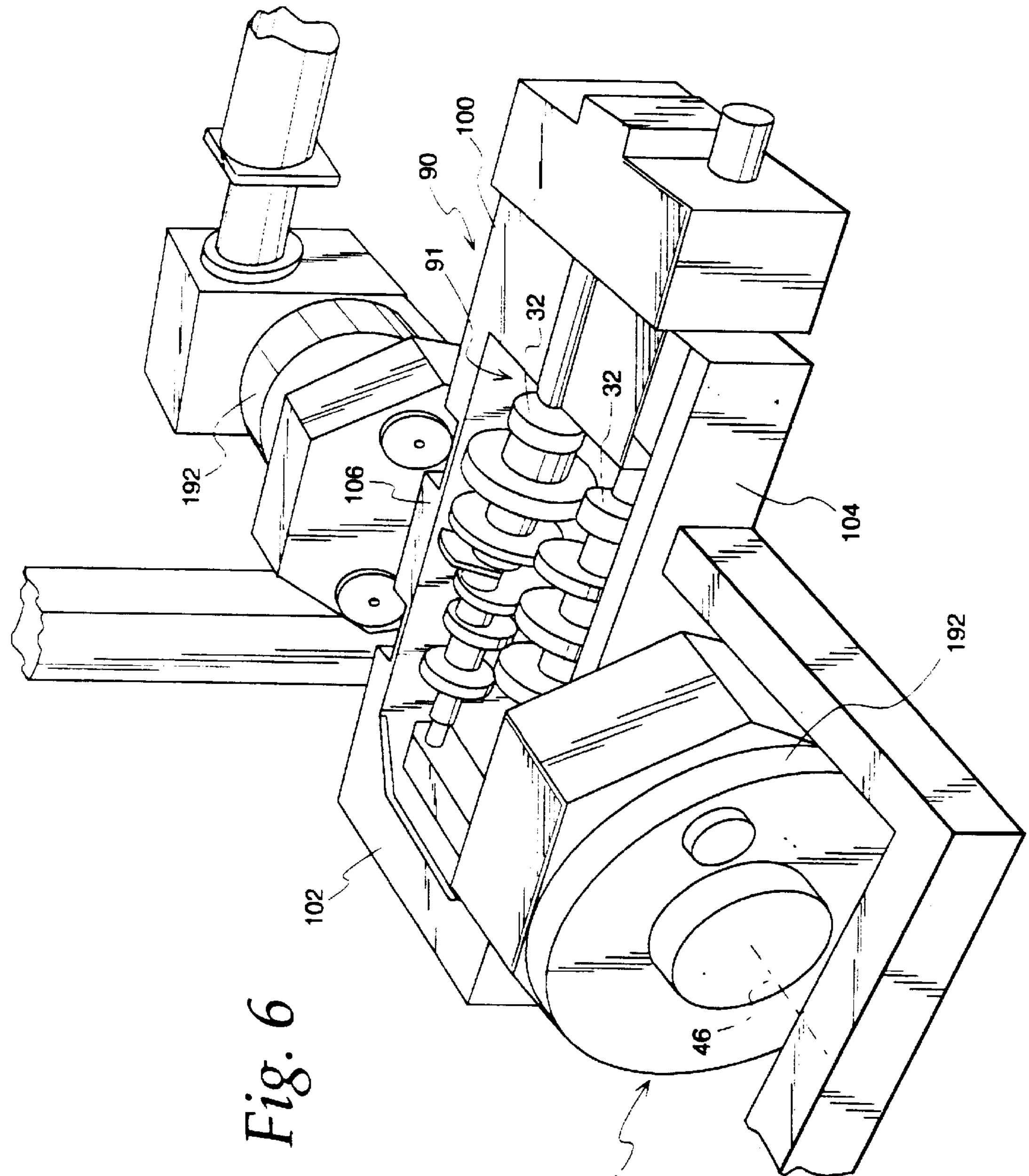

Fig. 6

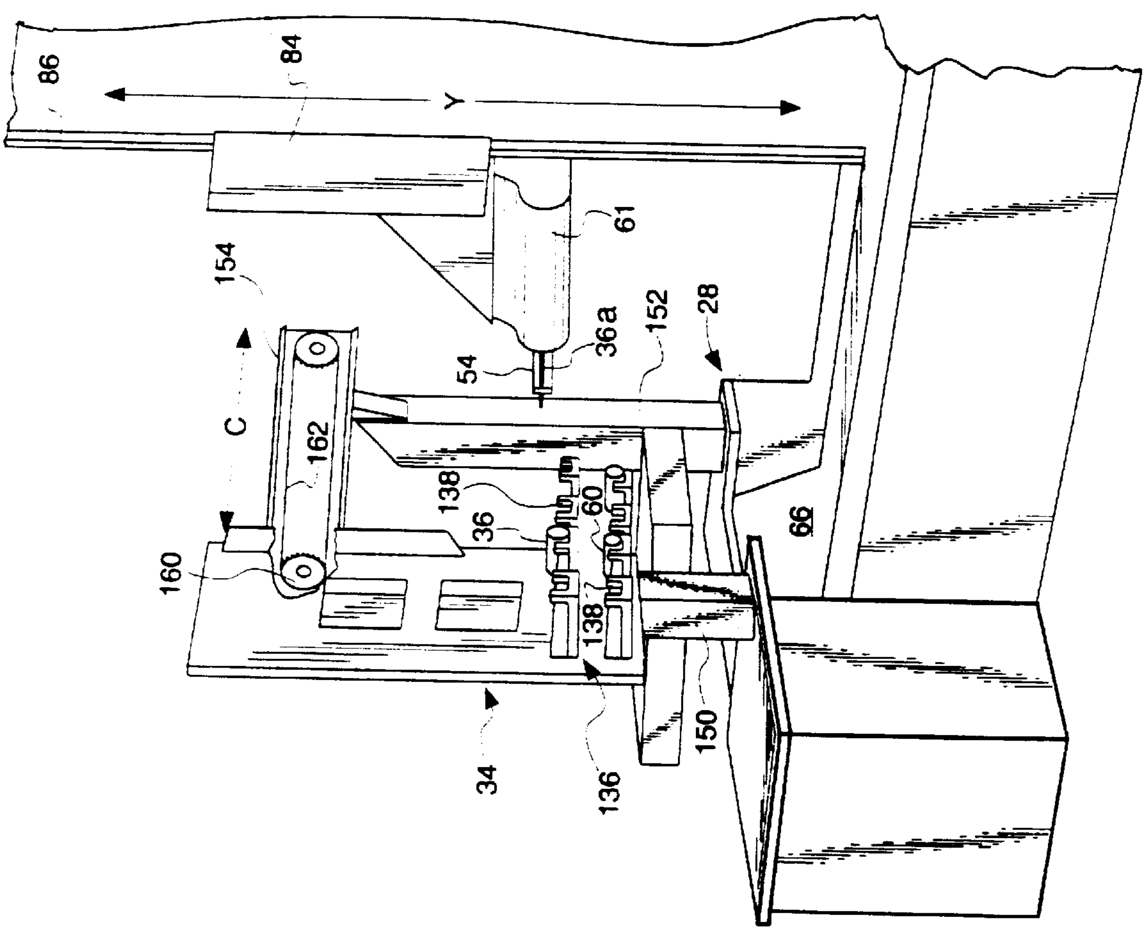

Fig. 7

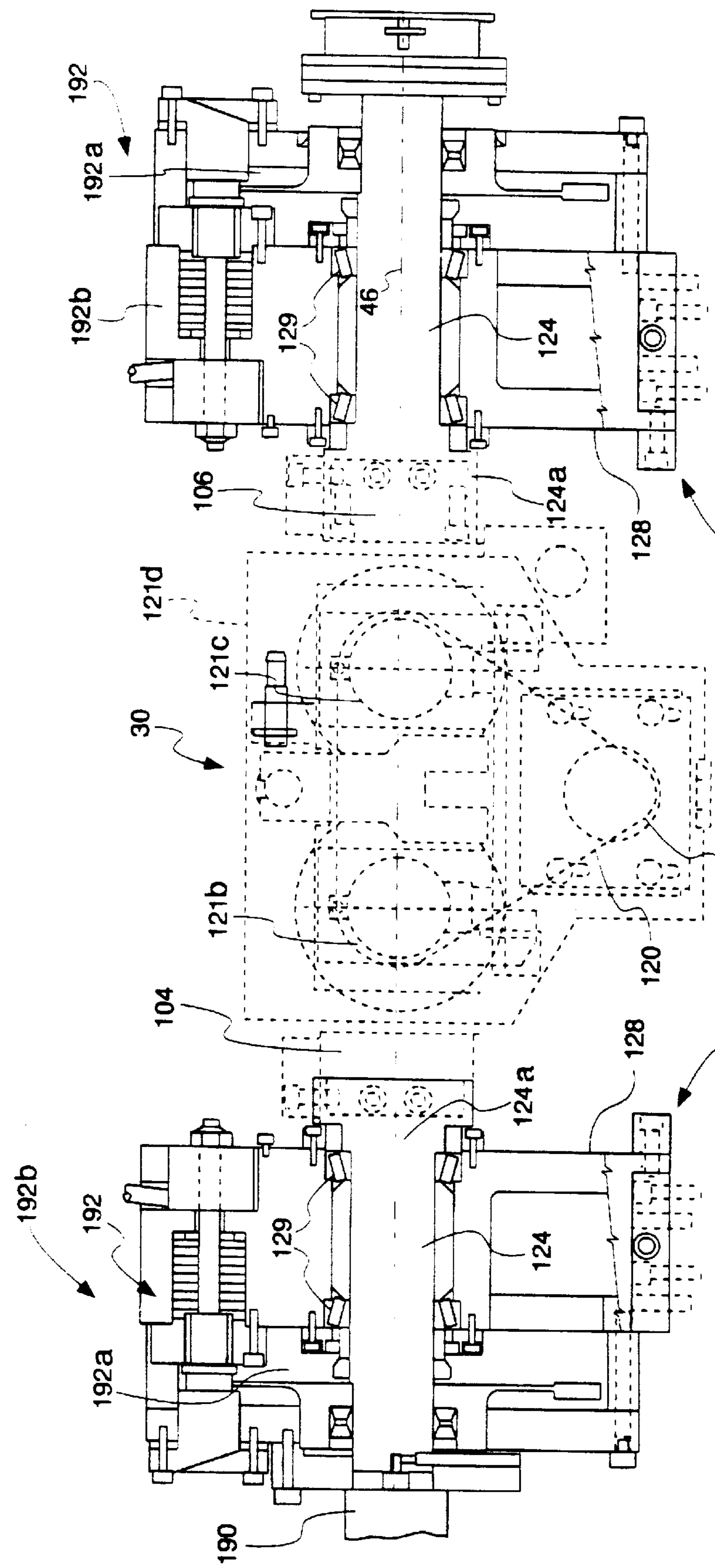
192
192a
192b
46
129
124
106
124a
128
66
121d
121C
30
121a
120
121b
104
190

Fig. 8

METHOD AND APPARATUS FOR MACHINING HOLES IN CRANKSHAFTS

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

BACKGROUND OF THE INVENTION

This invention relates to a method and apparatus for machining holes in crankshafts, and more particularly, for machining holes in crankshafts on a production scale basis.

Currently, crankshafts for automobile engines, truck engines or the like are manufactured and machined in large production quantities on a multi-station transfer line, each station of which is dedicated to machining one or more holes, such as oil holes, in the crankshafts. The transfer line works relatively well in that the same crankshaft for a given production model will have identically located oil holes for thousands and thousands of crankshafts which are machined. A particular problem is that the transfer line does not lend itself to changes in engine design where it is desirable to change the engine stroke thereby changing the particular angular position and location of the oil holes in the crankshafts relative to the crankshaft axis. The transfer lines are very long, expensive and time-consuming to build and install. Large and expensive fixtures must be built and be precisely positioned at each of the transfer stations, each of which has a machine head with a hole machining tool or tools. The ability to modify engines or to change the angle and the location of the crankshaft oil holes is a limitation that is difficult to overcome when machining oil holes in a transfer line.

It will be appreciated that such transfer lines are not well adapted to handle various sizes and shapes of crankshafts as well as to more modest changes in the same crankshaft. Additionally, the oil holes may be anywhere along and across the axial length of the crankshaft and at different rotational positions about the circumference of the crankshaft. Thus, dedicated transfer lines do not provide the desired flexibility with respect to adapting to very significant changes in position and angle of the cutting tool with respect to the crank's longitudinal axis as well as to a rotational position about the circumference of the crankshaft.

On the other hand, the typical or standard cutting machine with three axes of movement is also not well suited for machining crankshafts. In such three axis machines the cutting tool is normally plunged along a given axis, vertical or horizontal. If the cutting tool for drilling of the oil holes is moved horizontally along an X or plunging axis, then it is also standard three-axis machine are able to move vertically in a Y direction normal to the horizontal plunge axis to change the height or the location of the hole along the longitudinal length of the crankshaft. The movement in the third orthogonal plane is usually or may be called a Z axis and would be a movement in the horizontal plane normal to the plunging axis. However, such machines can not readily machine oil holes anywhere along the length of the crank and at any angle through the crankshaft.

Thus, there is a need for a new and more flexible apparatus for machining oil holes in crankshafts.

SUMMARY OF THE INVENTION

In accordance with the present invention, an apparatus and method are provided in which a crankshaft is rotated about its longitudinal axis and is tilted relative to a fixed plunging axis of a cutting tool to machine oil holes at various positions and angles through the crankshaft. The cutting tool may also be moved along and across the length of the crankshaft to cut a hole anywhere along and across the axial length of the crankshaft. This is achieved by having the cutting tool travel along a fixed axis, and by mounting the crankshaft in a workholder or fixture in which the workholder and crankshaft tilt or pivot relative to the plunging axis of the cutting tool; and in which the crankshaft is spun about its longitudinal axis to the peripheral location for entry of the cutting tool. To provide oil holes anywhere along and across the axial extent of the crankshaft, the cutting tool may be moved in directions normal to the tool's plunge axis. Thus, in the preferred embodiment of the invention, the crankshaft is mounted in a fixture or workholder; and the fixture is pivoted to change the angle of the crankshaft to the plunging axis and the crankshaft is spun about its longitudinal axis to allow entry of the tool anywhere about the circumference of the crankshaft. To locate the hole position along and across the axial length of the crankshaft, the tool head is shifted vertically and horizontally relative to the crankshaft.

In accordance with the present invention, the position and angle of the oil holes may be changed by controlling the software electronic controls which control the rotational spin axis location, the degree of tilt of the crankshaft, and the location of the plunge axis relative to the length and breadth of the crankshaft.

It is preferred that the fixture or workholder have a headstock and a tailstock therein for rotatably mounting the crankshaft, and also have an open face on one side thereof to permit loading or unloading of a crankshaft through the open face.

In accordance with one aspect of the invention, a bushing for guiding the cutting tool into the crankshaft is positioned relative to the crankshaft and the cutting tool by a bushing support. The bushing support utilizes a feed mechanism to advance and to retract the bushing relative to the crankshaft and to maintain the bushing in correct relative position independent of the plunge axis during machining of holes.

In accordance with an important aspect of the invention, the machine is particularly adaptable for machining different crankshafts in that it uses different cutting tools and supporting bushings therefor from an inventory of tools and bushings carried in an automatic storage and dispensing device, such as wine rack which stores tools and bushings for each of the particular hole configurations. That is, the machine tool is able to select different tools and bushings for each of the particular hole configurations for a given crankshaft; and of course, if a different size, shape or type of crankshaft is used, the inventory of bushings and cutting tools may be changed to provide the appropriate tools for the different crankshafts.

Preferably, an automatic toolchanger is mounted at a position remote from the machining head; and the fixture is titled to enlarge a space between it and the machine head. The tool changer is then shifted into this enlarged space between the fixture and the tool head, and then the tooling is changed and the tool changer is returned to its remote position.

In accordance with another important aspect of the invention, the production capability of the apparatus is increased by mounting a plurality of crankshafts side by side in a tiltable and rotatable fixture so that multiple crankshafts are machined simultaneously by multiple tools traveling along parallel plunging axes. This provides for the increased production from a single machine.

Thus, it will be seen that the present invention is particularly directed to the use of flexible software and to machine control technology to rapidly spin and tilt the crankshafts and to shift the cutting tool to each of the various positions needed for the oil holes.

The preferred crankshaft machine is a seven axis machine with a pair of crankshafts being mounted in a fixture that pivots about a centrally located pivot axis or trunnions relative to a fixed plane containing the plunging axis, with the crankshafts being rotated or spun in the fixture about their respective axial axes. The pair of cutting tools are mounted to move in a first plunging direction which direction is normal to the directions in which the tool head shifts relative to the crankshaft's length and breadth to position the holes anywhere along and across the lengths of the crankshafts and at any angle to the axes of the crankshafts. It is much quicker and easier to be able to change the control and signal positions than to physically change dedicated transfer line equipment.

BRIEF DESCRIPTION OF THE DRAWINGS

This and other advantages of the invention will become apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. **1** is a front perspective view of an apparatus for machining holes in crankshafts at various positions and angular orientations and embodying the present invention;

FIG. **2** is a front elevational view of the apparatus of FIG. **1** and includes the pivoting fixture that holds and rotates the crankshafts;

FIG. **3** is a front elevational view with the details of the crankshaft holding fixture removed so that the machine stack, machine heads, cutting tools, and bushings may be seen in greater detail;

FIG. **4** is a plan view of the crankshaft fixture;

FIG. **5** is a side elevational view of the crankshaft fixture;

FIG. **6** is a simplified perspective view of the crankshaft holder in its crankshaft removal or receiving position; and

FIG. **7** is a simplified, perspective view of the automated tool holder for tools and bushings; and

FIG. **8** is a cross-sectional view through trunnion shafts and bearings mounting the fixture for tilting movement

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

As shown in the drawings for purposes of illustration, the invention is embodied in a multi-axis machining apparatus **20** for machining holes in a crankshaft **32** (FIG. **4**). As best seen in FIG. **1**, the apparatus includes a three-axis machine stack **22** for translating cutting tools **36**a and **36**b operably held by a machine head **24** mounted to the machine stack **22**. The machine stack **22** and a fixture **30** for holding and rotating a pair of crankshafts **32** are mounted on a frame or machine base **28**. An automatic tool changing and loading apparatus **34** provides means for storing a plurality of cutting tools **36** including the cutting tools **36**a and **36**b to machine various hole configurations and means for automatically changing tools to be operably held by the machine head **24**. Software driven electronic controls are used to control the three-axis capabilities of the machine stack **22**, the rotating capabilities of the fixture **30**, and the automatic loading apparatus **34** to position the crankshaft **32** and an appropriate cutting tool **36**a relative to each other for machining of holes in the crankshaft **32** at various locations and angular orientations.

The crankshaft **32** has a longitudinal axis **40** (FIG. **3**) about which the crankshaft will rotate when it is in an engine. Various oil holes **41** (FIGS. **4** and **5**) need to be machined into the crankshaft, often at acute angles to the crankshaft, as shown in FIGS. **4** and **5**, to the longitudinal axis and several oil holes need to be machined along the length of the crankshaft. The oil holes may also be at different rotational positions or locations about the crankshaft circumference such that the crankshaft needs to be turned relative to the tool in order to machine the oil holes at different circumferential locations about the crankshaft. With changes in engine stroke, the oil holes may be relocated at different circumferential locations, at different angular tilts relative to the axis, and/or at different locations along to the length of the crankshaft. Improved apparatus to provide these desired changes with the requisite machining accuracy and production capabilities are needed.

In accordance with the present invention, each crankshaft **32** is readily positioned relative to the by a cutting tool **36**a in the machine head **24** in a fixture **30** which has rotational means for rotating the crankshaft **32** about its longitudinal axis **40** and tilt and pivoting means **44** for tilting the crankshaft **32** about a horizontal axis **46**. Directional arrow A (FIGS. **1** and **3**) illustrates the tilting angular movement about the horizontal axis **46** of the fixture **30**. The rotational means turns the crankshaft **32** about its longitudinal axis as indicated by the directional arrow B in FIG. **3**. Thus, holes **41** may be machined at various rotational positions about the circumference of the crankshaft **32** and holes may be machined at various angles relative to the longitudinal axis **40**. Each of the cutting tools **36**a and **36**b is movable relative to the crankshaft to machine holes along the length of the crankshaft.

Movement of the stack **22** with the cutting tools **36**a and **36**b thereon toward or from the crankshafts **32** for machining of holes to a depth is preferably along a horizontal plunging axis Z which is one of the three axes of the machine stack **22**. The cutting tool may be shifted laterally along a second horizontal axis X of the machine stack **22**, normal to the plunging axis Z, to position the cutting tool relative to the crankshaft **32** for machining holes offset from the rotational axis **40** of the crankshaft **32**. The cutting tool may also be shifted along the third axis of the machine stack, which is a vertical axis Y. This axis Y is used to position the cutting tool relative to the crankshaft **32** for machining of holes anywhere along the axial extent of the crankshaft **32**.

To provide the repetitive accuracy for the oil holes to be machined quickly and to the close tolerances needed, it is preferred to provide bushings **60**, for guiding the cutting tools **36**a and **36**b into the crankshaft **32**. The bushings are positioned relative to the crankshaft **32** and the cutting tools **36**a and **36**b by a bushing support **54** mounted to the machine stack **22** adjacent to the machine head **24**. The bushing support **54** includes positioning means **56** for advancing and retracting bushings **60** up to the crankshaft **32**, along a W axis that runs co-axial with plunging axis Z, but is independent of plunging axis Z. As the cutting tool plunges deeper into the crankshaft **32**, the positioning means **56** retracts the bushings **60** to be closer to the drive head **61** for the cutting tools relative to the crankshaft **32**, allowing the bushings **60** to guide the cutting tools into the crankshaft **32** for increased machining accuracy.

In order to provide the flexibility to change hole sizes or machining operations to each of the holes being machined, the apparatus preferably includes automatic loading apparatus **34** for storing cutting tools **36** and associated bushings **60** for each of the particular hole configurations for a given crankshaft and means for transferring the cutting tools **36** to the machine head **24** and the bushings **60** to the bushing support **54**. This allows the machining apparatus **20** to select different cutting tools **36** and bushings **60** for each of the particular hole configurations for a given crankshaft. The machining apparatus **20** is particularly adaptable for machining different crankshafts as the inventory of cutting tools **36** and associated bushings **60** may be changed to provide the appropriate tools for machining crankshafts of different design.

Software-driven electronic controls are used to control the three axes Z, X, Y of the machine stack **22**, the rotation about axis B and tilting about axis A of the crankshaft **32** and the fixture **30**, positioning along axis W of the bushing support **54**, and the automatic tool changing and loading apparatus **34** to position appropriate cutting tools **36** and bushings **60** relative to a crankshaft **32** for machining of holes in the crankshaft **32**. Thus, when changing the stroke of an engine or changing from one form of crankshaft to another form of crankshaft, the software may be used to relocate the holes without physically having to relocate fixtures, add new fixtures, etc., as in transfer line machining of crankshafts.

In accordance with an important aspect of the invention, the production capability of the machining apparatus is increased by mounting a plurality of crankshafts **32** side by side in the fixture **30**, as shown in FIG. **4**, and by mounting a plurality of machine heads **24** with cutting tools **36**a and **36**b to the machine stack **22**, as shown in FIGS. **1** and **3**. The crankshafts **32** are spun in angular directions B about their respective, longitudinal axes **40** in the fixture **30**; and the fixture **30** is tilted in angular direction A about a horizontal axis **46**. This allows multiple crankshafts **32** to be machined simultaneously by multiple cutting tools traveling along parallel plunging axes Z.

Turning now in greater detail to the description of the invention, as best shown in FIG. **1** and FIG. **3** of the drawings, the three-axis machine stack **22** is driven for sliding movement in the machine base or frame **28** along the plunging axis Z by a motor (not shown) which is mounted behind the stack **22** on a stationary base **66** of the frame **28**. The motor Z-axis includes feedback devices connected to circuitry that precisely positions and controls the motor. The motor is connected to a horizontal drive screw **68** (FIG. **1**) threaded in a nut in the stack **22** to shift the stack. The end of the Z-axis drive screw **68** is mounted for turning in a block **68**a on the stationary base **28**. The stack **22** is guided for travel in the plunging axis direction Z by its linear roller bearings **64** which are slidable along guide rails **74** on the frame **28**. The machine head **24** is driven vertically with respect to the first carriage along the vertical axis Y by a motor **76** and its feedback means, which are secured to the stack **22** and rotate through a coupling to a vertically-extending screw **78** threaded in a nut mounted on a machine head carriage **82**. The machine head carriage is guided for travel relative to the first carriage in the vertical axis direction Y by its linear bearings **84** which slide along vertical fixed guide rails **86** on the first carriage **70**.

Lateral movement of the machine head **24** along the lateral or second horizontal axis X is provided by a motor **88** (FIG. **3**) and its feedback device (and circuit means) which are mounted to the second carriage **82**. The motor **88** and is connected to a horizontal screw **89** turning in a nut **92** mounted on a third carriage **94** which is guided for travel in the second horizontal direction X by its horizontal linear bearings **96**. These third carriage slide bearings engage and slide horizontally on guide rails **98** on the second carriage **82**.

The machine head **24** is carried by the third carriage **94** for shifting horizontally in relation to the rotational axis **40** of the crankshafts **32** by movement of the third carriage **94** along the second horizontal axis X. Because the machine head and third carriage are mounted on the second carriage **82**, movement of the second carriage vertically shifts the tool **36**a along the axial extent of the crankshafts **32** by movement of the second carriage **82** along the vertical axis Y. Because the tool head and second carriage **82** are mounted on and carried by the first carriage, the tool **36** may be moved toward or from the crankshaft by movement of the first carriage **70** along the plunging axis Z. Thus, movement of the cutting tool **36**a, operably held by the machine head **24**, along the plunging Z, second horizontal X, and vertical Y axes is provided by the machine stack **22** mounted to the frame **28**.

In order for the pair of plunging tools **36**a to have access to the crankshafts **32** anywhere intermediate the ends of the respective crankshafts while they are mounted in fixture **30**, the fixture preferably is in shape of a box-shaped, open frame **90** (FIG. **6**) with a large center, rectangular opening face **91** to expose the crankshafts throughout substantially their entirety. This open box-shaped frame **90** is mounted for tilting about the pivot start axis **46** by the pivot or tilting means **44** located at the horizontal pivot axis **46** which, in this instance, is centrally located between upper and lower ends of the fixture frame **90**.

As best seen in FIGS. **1**, **2**, **4** and **6**, the fixture frame **90** is defined by an upper beam member **100**, a lower beam member **102**, a left side beam member **104**, and a right side beam member **106**. The four beam members define a rectangular, box-like frame **90** to support the crankshafts, headstocks, tailstocks and motor to rotate the crankshafts. The four beam members constitute a part of the fixture that is trunnion mounted to tilt about axis A. Thus, the support frame **90** of the fixture **30** has a generally rectangular shape with a open central area for mounting the crankshafts **32** and for providing maximum cutting tool access to the crankshafts **32**.

Tilting of the fixture **30** relative to the plunging axis of the cutting tools **36**a and **36**b is provided by the pivots means **44** which include the stub shaft trunnions **124** (FIG. **8**) fixed to the centers of the left and right **106** beam members **104** and **106** of the fixture **30**. The stub shaft trunnions extend horizontally outward from the left and right beams **104** and **106** and are journaled in large bearings in stationary bearing mounts **128** each fastened at their lower ends to the top of the stationary base **66**. The stub shafts trunnions are fixed to the beams at their inner ends **124**a so that the turning of the trunnions also turns the beams and thereby the carrier about the tilt axis through the centers of the trunnions. The trunnions are supported for turning in large bearings **129** (FIG. **8**) in bearing mounts **128** secured at their lower bases to the frame base **66**. These large and heavy trunnions and bearings mount the fixture frame for precise tilting. As best seen in FIG. **1**, the right trunnion **124** is driven by a driven by a motor **132** that is precisely positioned and controlled. Suitable feedback devices which include an encoder **190** are connected to the end of the left-hand stub shaft trunnion **124** to provide exact information as to the tilt location of the fixture and crankshafts. The motor **132** is mounted on the frame base **66**.

To precisely hold the trunnions **124** and fixture **30** against rotation during machining, hydraulic brakes **192** have a first rotatable portion **192**a secured to the trunnion shafts and a second stationary portion **192**b secured to the bearing mount **128**. The hydraulic brake **192** is actuated by fluid in a hydraulic brake line **194** to lock the trunnion shafts and thereby the fixture against movement during the drilling of holes **41** in the crankshafts.

The fixture **30** may be rotated to a crankshaft receiving position such as shown in FIGS. **4** and **6**, where the fixture is generally horizontal and presents an open face that allows crankshafts to be loaded through the open face thereof. When the fixture **30** is tilted to present the crankshafts to the tools, as shown in FIG. **1** for machining, the underside of the fixture has been rotated to an upper position with a motor **118**, slide rods **127** and crankshaft cradle blocks **170** and **172** being uppermost, thereby preventing a lifting of the crankshafts by an overhead gantry, not shown. As will be explained, the motor, slide rods and cradle blocks are all on the underside of the fixture so that an open face **91** on the upper side of the fixture is available for removal of machined crankshafts from the cradle blocks, and the insertion of new crankshafts into the cradle blocks in the fixture.

The crankshafts are rotated simultaneously about their respective longitudinal axes **40** by a motor **118** (FIGS. **1** and **5**) which is mounted on the underside of the fixture **30**. The motor **118** has a drive shaft **119** which turns a sprocket **121**a meshed with a drive timing belt **120**. The timing belt is also entrained about sprockets **121**b and **121**c, which are mounted on the ends of headstock shafts **122** rotatable in headstocks **123**. The sprockets and timing belt are covered by a triangular-shaped cover **121**d (FIGS. **1** and **8**). Encoders **180** (FIG. **5**) are connected on the ends of the headstock shafts **122** to read the exact rotational position of the crankshaft. The headstocks are secured to a stationary end plate and top beam member **100** of the fixture **30**, and weight of the headstocks is also supported by a cross bar **124** spanning the side beam members **104** and **106** of the fixture **40**. The headstocks have ends **108** for centering and engaging upper ends of the crankshafts and for imparting a rotating torque to the crankshafts. At their opposite ends, the crankshafts are each rotatably mounted in a tailstock **125**. The tailstocks **125** are each mounted in a slide bar or carrier **126**. As best seen in FIG. **1**, the slide bar **126** is mounted for sliding in the longitudinal direction along a pair of parallel slide rods **127** that are fixed to extend longitudinally along the underside of the fixture **30**. The parallel slide rods **127** have lower ends (FIG. **1**) mounted on a transverse plate **129** which is fixed to lower end beam **102** of the fixture frame. Upper ends of the slide rods **127** are fixedly secured to the upper transverse bar **124** which spans across and is secured to the side beams **104** and **106** of the fixture frame.

To shift the tailstocks **125** and their slide carrier **126** along the slide rods **127**, a motor such as a hydraulic cylinder **132** is provided and is mounted on a transverse, stationary fixture plate **133** (FIGS. **1** and **5**) which is bolted to the fixture side beams **104** and **106**. The hydraulic cylinder **132** has a piston rod **134** connected by a coupling **184** to an axially aligned rod **185**. When the hydraulic cylinder is actuated, it retracts its piston rod **134** and attached rod **185**, and pulls the slide carrier **126** along the parallel slide bars **127** toward the motor and headstock. The lower end of the rod **185** projects through a bore in the tailstock support bar **126**. When the piston rod **134** and attached rod **185** are pulled toward the motor, springs **186** are compressed between a collar **185**a on the rod **185** and cradle plate **188**. When the actuating cylinder force is released, the springs **186** shift the cradle plate **188** and the cradle blocks **170** and **172** are connected thereto toward the tailstock. Thus, the crankshafts are supported on the cradle blocks **170** and **172** that slide on the parallel slide rods **127**. The cradle blocks support the crankshafts during removal of a machined crankshaft and after the placement of a new crankshaft for machining on the cradle blocks and prior to engagement of the headstock and tailstocks with the ends of the crankshaft.

As best seen in FIGS. **1**, **3** and **7**, the automatic loading apparatus **34** stores cutting tools **36** and associated bushings **60** in a matrix rack **136**, commonly known as a wine rack, mounted to the frame **28** with a front face of the wine rack **136** facing away from the machine stack **22** and a back face of the wine rack **136** facing towards the machine stack **22**. The wine rack **136** includes a matrix of storage positions **138**, each containing a pair of cutting tools **36** and their associated support bushings **60**. The wine rack **136** has a sufficient number of storage positions to store all the cutting tools **36** and associated bushings **60** required to machine each of the particular hole configurations for a given crankshaft **32**. Each cutting tool **36** is mounted in a tool holder having a front end for holding the cutting tool and a back end with a tapered shank for operable engagement with the machine head **24**. Each bushing **60** has a front end for guiding the cutting tool **36** into the crankshaft **32** and a back end with a tapered shank for engagement with the bushing support **54**. Each cutting tool **36** and associated bushing **60** are mounted together in a storage position with the cutting tool **36** fully engaged with its associated bushing **60**. The fronts of the tool holder **140** and the bushing **60** face the front of the wine rack **136**, with the tapered shanks of both the tool holder **140** and bushing **60** extending from the back of the wine rack **136** for respective engagement with the machine head **24** and the bushing support **54**.

The automatic loading apparatus **34** transfers cutting tools **36** and associated bushings **60** from a storage position in the wine rack **146** to the machine head **24** and to the bushing support **54**. To this end, the vertical wine rack **146** is mounted at a location behind an outer vertical pillar **150** when the wine rack is in its non-tool changing position. The wine rack is slidably mounted on the base **66** of the frame **28** to travel from the remote non-tool changing position of FIG. **1** to a tool and bushing changing position (not shown) between the tool head and the crankshaft fixture. In order to provide the space to receive the wine rack, the crankshaft fixture is first rotated to a vertical position. A second frame vertical pillar **152** supports an upper, horizontal bridge **154** which is supported at its opposite end by the first pillar **150**. Mounted within the hollow bridge **154** is a drive means **156** for sliding the tool carrier in the X and U axis direction. Herein, the drive means includes a motor **160** mounted on the bridge with its motor shaft driving an endless chain **162** that extends between the drive sprocket **161** driven by the drive motor **160** and a sprocket **163** mounted on the stack **22**. A drive bracket fixed to the chain extends laterally and is secured to the wine rack so that as the chain **162** travels along a "U" axis for shifting, the wine rack is pulled along the U-axis. The U-axis is parallel to the "X" axis movement of the tool head. The wine rack is guided for sliding along the "U" axis by upper slides on the wine rack and bridge and lower bronze guide slides sliding on the stationary base frame **24**.

The automatic loading apparatus **34** transfers cutting tools **36**a and **36**b and bushings **60** from a storage position in the wine rack to the machine head **24** and to the bushing support **54**. When the wine rack is in its tool and bushing transfer position, the machine stack **22** then translates the machine head **24** and bushing support **54** forward into engagement with the respective tapered shanks of the tool holder **140** and the bushing **60**. The machine head **24** and bushing support **54** are then translated upward to lift the cutting tool **36** and associated bushing **60** from the wine rack **136**. Transfer of a cutting tool **36** and associated bushing **60** from the machine head **24** and bushing support **54** back to the wine rack **138** is performed in a similar fashion, with the machine stack **22** translating the machine head **24** and bushing support **54** into position so that they can place the cutting tool **36** and bushing **60** into the appropriate storage position **138**.

The present invention is particularly directed to the use of flexible software and machine control technology to rapidly select appropriate tools, spin and tilt the crankshafts **32**, and shift the tools to each of the various positions needed for machining holes in a crankshaft **32**. It is much quicker and easier to change the software driven electronic controls of the machining apparatus **20** than to physically change dedicated transfer line equipment.

What is claimed is:

[**1**. An apparatus for machining holes in crankshafts at various angular positions about a longitudinal axis through the crankshaft and at various tilt angles to the rotational axis, comprising:

a frame;

a rotational means on the frame for supporting a crankshaft and for rotating the crankshaft about the crankshaft's longitudinal axis to present different angular positions for the machining of holes;

a machine head mounted on the frame with a tool, movable along a plunging axis to present the tool to the crankshaft to machine holes therein; and

tilt means on the frame mounting the crankshaft to tilt the crankshaft at various angles to the plunging axis so that holes may be machined at various rotational positions about the crankshaft and at various tilt angles to its longitudinal axis.]

[**2**. An apparatus in accordance with claim **1** wherein rotational means comprises a crankshaft supporting fixture, means in the fixture mounting the crankshaft for turning about the rotational axis of the crankshaft within the fixture; and wherein the tilt means includes pivot means on the frame for pivotally mounting the fixture to pivot relative to the plunging axis.]

[**3**. The apparatus of claim **2** wherein a slide means of the machine frame guides the machine head for travel along the plunging axis, another slide means of the machine frame guides the machine head for travel along a first positioning axis normal to the plunging axis, and another slide means of the machine frame guides the machine head for travel along a second positioning axis that is normal to both the first positioning axis and the plunging axis.]

[**4**. The apparatus of claim **1** further comprising means for storing a plurality of tools and tool support bushings, adjacent the machine head for automatic transfer of different tools to the machine head.]

[**5**. The apparatus of claim **1** further comprising means for positioning a tool support bushing in correct position between the crankshaft and the tool.]

6. [An apparatus of claim **1** wherein] *An apparatus for machining holes in crankshafts at various angular positions about a longitudinal axis through the crankshaft and at various tilt angles to the rotational axis comprising:*

a frame:

a rotational means on the frame for supporting a crankshaft and for rotating the crankshaft about the crankshaft's longitudinal axis to present different angular positions for the machining of holes;

a machine head mounted on the frame with a tool, movable along a plunging axis to present the tool to the crankshaft to machine holes therein;

tilt means on the frame mounting the crankshaft to tilt the crankshaft at various angles to the plunging axis so that holes may be machined at various rotational positions about the crankshaft and at various tilt angles to its longitudinal axis;

a second rotational means [is] provided on the fixture for supporting a second crankshaft for synchronous rotational positioning of the second crankshaft with the first crankshaft; and

a second machine head is provided having a tool, synchronously movable with the first machine head along the plunging axis to present tools to the pair of crankshafts after the crankshafts have been rotatably positioned and tilted relative to the plunging axis.

7. [The apparatus of claim **1**, wherein] *An apparatus for machining holes in crankshafts at various angular positions about a longitudinal axis through the crankshaft and at various tilt angles to the rotational axis, comprising:*

a frame:

a rotational means on the frame for supporting a crankshaft and for rotating the crankshaft about the crankshaft's longitudinal axis to present different angular positions for the machining of holes;

a machine head mounted on the frame with a tool, movable along a plunging axis to present the tool to the crankshaft to machine holes therein;

tilt means on the frame mounting the crankshaft to tilt the crankshaft at various angles to the plunging axis so that holes may be machined at various rotational positions about the crankshaft and at various tilt angles to its longitudinal axis; and

pivot means on the frame are provided and the tilt means comprise a fixture mounted on the pivot means for tilting about an axis through the pivot means.

[**8**. An apparatus for machining holes in crankshafts at various angular positions about a longitudinal axis through the crankshaft and at various tilt angles to the rotational axis, comprising:

a frame;

a fixture on the frame having means for supporting a crankshaft for rotational positioning of the crankshaft about the crankshaft's longitudinal axis;

means on the fixture for turning the crankshaft in a first, angular direction about the crankshaft's longitudinal axis while the crankshaft is supported in the fixture to present different peripheral surface sections of the crankshaft;

a first machine head for carrying a tool, movable along three axes;

the first axis being a vertical axis for positioning the tool vertically relative to the crankshaft;

the second axis being a horizontal axis for positioning the tool horizontally relative to the crankshaft;

the third axis being a horizontal plunging axis which is normal to the first and second axes, for presenting the tool to the crankshaft; and

tilt means on the frame for tilting the fixture and the crankshaft carried thereon through a second angular rotation about a tilt axis and relative to the plunging axis to machine holes at various angles to the longitudinal axis and at various peripheral locations about the crankshaft.]

9. [The apparatus of claim **8** further comprising:] *An apparatus for machining holes in crankshafts at various* *angular positions about a longitudinal axis through the crankshaft and at various tilt angles to the rotational axis, comprising:*

a frame;

a fixture on the frame having means for supporting a crankshaft for rotational positioning of the crankshaft about the crankshaft's longitudinal axis;

means on the fixture for turning the crankshaft in a first, angular direction about the crankshaft's longitudinal axis while the crankshaft is supported in the fixture to present different peripheral surface sections of the crankshaft;

a first machine head for carrying a tool, movable along three axes;

the first axis being a vertical axis for positioning the tool vertically relative to the crankshaft;

the second axis being a vertical axis for positioning the tool horizontally relative to the crankshaft;

the third axis being a horizontal plunging axis which is normal to the first and second axes, for presenting the tool to the crankshaft; and

tilt means on the frame for tilting the fixture and the crankshaft carried thereon through a second angular rotation about a tilt axis and relative to the plunging axis to machine holes at various angles to the longitudinal axis and at various peripheral locations about the crankshaft;

a second machine head having a tool, synchronously movable with the first machine head along three axes; and

wherein, the fixture has means for supporting a pair of crankshafts for the synchronous rotational positioning of the crankshafts about the crankshafts' longitudinal axes.

10. An apparatus for machining holes in crankshafts at various angular positions about a longitudinal axis through the crankshaft and at various tilt angles to the rotational axis, comprising:

a frame;

a fixture having means for supporting a plurality of crankshafts for the synchronous rotational positioning of the crankshafts about the crankshafts' longitudinal axes;

tilt means on the frame including trunnions mounting the fixture for tilting in an angular direction about a horizontal axis through a central portion of the fixture to present the crankshafts at various tilt angles to the plunging axis;

means on the fixture for turning each of the crankshafts about their respective, longitudinal axes in a second angular direction while the crankshafts are supported in the fixture;

a plurality of machine heads having tools, synchronously movable along three axes: the first axis being a vertical axis for positioning the tools vertically relative to the crankshafts; the second axis being a horizontal axis, parallel to the axis of the trunnions, for positioning the tools horizontally relative to the crankshafts; the third axis being a plunging axis, normal to the first and second axes, for presenting the tools to the crankshafts after the crankshafts have been rotatably positioned about both the axis of the trunnions and the crankshafts' longitudinal axes;

means for storing a plurality of tools and tool support bushings, adjacent the machine heads for automatic transfer of different tools and tool support bushings to the machine heads; and

means for positioning the tool support bushings in correct position between the plurality of crankshafts and tools.

11. An apparatus for machining holes in crankshafts at various angular positions about a longitudinal axis through the crankshaft and at various tilt angles to the rotational axis, comprising:

a frame;

a crankshaft workholder mounted on the frame for supporting a crankshaft for rotation about the crankshaft's longitudinal axis to present different angular positions for the machining of holes;

a machine head mounted on the frame with a tool, movable along a plunging axis to present the tool to the crankshaft to machine holes therein;

tilt means on the frame mounting the crankshaft workholder to tilt the crankshaft workholder at various angles to the plunging axis so that holes may be machined at various rotational positions about the crankshaft and at various tilt angles to its longitudinal axis; and

an open face on one side of the crankshaft workholder to allow loading and unloading of a crankshaft when the workholder is tilted to a crankshaft loading position.

12. An apparatus in accordance with claim **11** wherein a headstock and a tailstock for rotating the crankshaft are mounted on the crankshaft workholder; and

means for moving the headstock relative to the tailstock to load or unload a crankshaft are on one side of the crankshaft workholder, leaving an opposite side open for lifting from an dropping into of crankshafts.

13. An apparatus in accordance with claim **11** wherein an automatic tool changer is movable from a remote position to a tool changing position between the crankshaft workholder and the machine head.

14. An apparatus in accordance with claim **13** wherein means on the frame guide the automatic tool changer to slide **35** laterally into a space created when the workholder is tilted to create more space between it and the machine head.

[15. A method of machining crankshafts comprising the steps of:

loading a crankshaft into a pivotable fixture;

tilting the fixture about a first tilt axis relative to a tool-plunging axis;

rotating the crankshaft in the fixture about the longitudinal, axis of the crankshaft to align the hole location with the plunging axis;

machining a first hole in the crankshaft;

moving a tool head carrying a tool in three orthogonal directions relative to the crankshaft in the fixture to position the tool for machining another hole along the length of the crankshaft;

machining a second hole in the crankshaft; and

unloading the crankshaft with machined holes therein.**]**

16. **[**A method of machining crankshafts in accordance with claim **15** including the step of**]** *A method of machining crankshafts comprising the steps of:*

loading a crankshaft into a pivotable fixture;

tilting the fixture about a first tilt axis relative to a tool-plunging axis;

rotating the crankshaft in the fixture about the longitudinal axis of the crankshaft to align the hole location with the plunging axis;

machining a first hole in the crankshaft;

moving a tool head carrying a tool in three orthogonal directions relative to the crankshaft in the fixture to position the tool for machining another hole along the length of the crankshaft;

machining a second hole in the crankshaft;

unloading the crankshaft with machined holes therein; and

loading a pair of crankshafts in the fixture and machining each of the crankshafts simultaneously.

[**17**. A method of machining crankshafts in accordance with claim **15** including the step of providing a machine tool having at least three axes with the plunging axis being a horizontal axis, and in which the step of moving the tool relative to the crankshaft includes the step of shifting the tool head vertically along a vertical axis.]

18. A method of machining crankshafts comprising the steps of:

positioning a crankshaft fixture to have an open face facing upwardly to receive at least one crankshaft therein;

loading at least one crankshaft into the fixture through the open face thereon;

tilting the fixture to present the crankshaft to a tool and at a predetermined angle to the longitudinal axis of the crankshaft;

rotating the crankshaft in the fixture to present a predetermined location on the crankshaft to be machined;

plunging the tool into the workpiece to machine a hole at the predetermined location and at the predetermined angle, to the longitudinal axis of the crankshaft;

removing the tool from the hole formed in the workpiece; and

tilting the fixture to position the crankshaft for removal from the fixture.

19. A method in accordance with claim **18** including the further step of providing an automatic toolchanger at a position remote from the machine head;

shifting the automatic toolchanger laterally into a space between the machine head and the fixture; and

automatically changing tools on the machine head.

20. A method in accordance with claim **19** including the step of rotating the fixture to shift a portion thereof from its crankshaft presenting position for machining to enlarge the space to accommodate the automatic tool changers lateral movement to the tool changing position between the fixture and the machine head. a pivotable mount for the support and for pivoting the crankshaft carried thereon about a pivot axis and relative to the plunging axis to allow holes to be machined at various angles to the longitudinal axis and at various peripheral locations about the crankshaft.

21. An apparatus for machining holes in a crankshaft at various circumferential positions about a rotational axis of the crankshaft and at various angles to the rotational axis the apparatus comprising:

a frame;

a first support on the frame for supporting a crankshaft for rotating about the crankshaft rotational axis to present different circumferential positions for machining of holes;

a first drive associated with the first support for rotating the crankshaft about its rotational axis so that holes may be machined at various circumferential positions about the crankshaft;

a machine head mounted on the frame with a tool movable along a plunging axis to present the tool to the crankshaft to machine holes therein;

a second support on the frame for supporting the crankshaft for shifting relative to the plunging axis so that holes may be machined at various angles relative to the rotational axis;

a second drive associated with the second support to shift the crankshaft relative to the plunging axis; and

a mount on the frame for mounting the second support for rotating about a horizontal axis.

22. An apparatus for machining holes in a crankshaft at various circumferential positions about a rotational axis of the crankshaft and at various angles to the rotational axis, the apparatus comprising:

a frame;

a first support on the frame for supporting a crankshaft for rotating about the crankshaft rotational axis to present different circumferential positions for machining of holes;

a first drive associated with the first support for rotating the crankshaft about its rotational axis so that holes may be machined at various circumferential positions about the crankshaft;

a machine head mounted on the frame with a tool movable along a plunging axis to present the tool to the crankshaft to machine holes therein;

a second support on the frame for supporting the crankshaft for shifting relative to the plunging axis so that holes may be machined at various angles relative to the rotational axis;

a second drive associated with the second support to shift the crankshaft relative to the plunging axis;

the second support having a crankshaft loading and unloading position; and

the second support and crankshaft being rotated from the loading and unloading position to machine holes at various angles to the plunging axis; and

a mount on the frame mounting the second support for rotating the crankshaft about a horizontal axis to machine holes at various angles to the plunging axis.

23. An apparatus for machining holes in a crankshaft at various circumferential positions about a rotational axis of the crankshaft and at various angles to the rotational axis, the apparatus comprising:

a frame;

a first support on the frame for supporting a crankshaft for rotating about the crankshaft rotational axis to present different circumferential positions for machining of holes;

a first drive associated with the first support for rotating the crankshaft about its rotational axis so that holes may be machined at various circumferential positions about the crankshaft;

a machine head mounted on the frame with a tool movable along a plunging axis to present the tool to the crankshaft to machine holes therein;

a second support on the frame for supporting the crankshaft for shifting relative to the plunging axis so that holes may be machined at various angles relative to the rotational axis;

a second drive associated with the second support to shift the crankshaft relative to the plunging axis;

a second machine head having a tool for machining a second crankshaft simultaneously while the first crankshaft is machined; and *the first support being a work support for supporting two or more crankshafts adjacent to each other for machining two or more crankshafts simultaneously with respective holes at the same angle to the axes of the crankshafts.*

24. An apparatus for machining holes in crankshafts at various rotational positions about a longitudinal axis through the crankshaft and at various angles to the longitudinal axis, the apparatus comprising:

a frame;

a support for supporting a crankshaft for rotational positioning of the crankshaft about the crankshaft's longitudinal axis;

a rotational drive carried by the support for turning the crankshaft about the crankshaft's longitudinal axis while the crankshaft is supported in the support to present different peripheral surface sections of the crankshaft for machining;

a first machine head for carrying a tool along a first vertical axis for positioning the tool vertically relative to the crankshaft;

a positioning mechanism that allows relative positioning between the machine head tool and crankshaft to be adjusted along a second horizontal axis;

the tool being positioned by the machine head along a horizontal plunging axis which is normal to the first and second axes, for presenting the tool to the crankshaft;

a pivotable mount for the support and for pivoting the crankshaft carried thereon about a pivot axis and relative to the plunging axis to allow holes to be machined at various angles to the longitudinal axis and at various peripheral locations about the crankshaft;

a second machine head having a tool, synchronously movable with the first machine head; and

the support comprising a fixture carrying a pair of crankshafts for the synchronous rotational positioning of the crankshafts about the crankshafts' longitudinal axes.

25. An apparatus for machining holes in a crankshaft at various angles relative to a longitudinal axis of the crankshaft, the apparatus comprising:

a machine head for carrying a tool that machines holes in the crankshaft;

a machine support that advances the tool along a plunging axis toward the crankshaft;

a crankshaft loading and unloading fixture having an open accessible side that can be shifted to allow for crankshaft loading and unloading operation; and

a drive for the fixture that shifts the open side between a first position with the open side generally facing upward to allow for overhead loading and unloading operations to take place in an unimpeded manner and a second position with the open side generally facing the machine head.

26. The apparatus of claim 25 wherein the fixture includes a pivot axis that extends normal to the plunging axis, and the drive Pivots the fixture about the pivot axis between the first and second positions.

27. The apparatus of claim 26 wherein the second position of the crankshaft fixture orients the crankshaft axis to be at various angles relative to the plunging axis for machining holes in the crankshaft at predetermined angles to the crankshaft axis.

28. The apparatus of claim 25 including a crankshaft support and associated drive that allow the crankshaft to be rotated about its longitudinal axis for machining holes at different circumferential positions about the crankshaft.

29. The apparatus of claim 25 wherein the crankshaft fixture has a pivot axis to allow the crankshaft to be inclined at predetermined angles relative to the plunging axis.

30. The apparatus of claim 25 wherein the crankshaft fixture includes a pair of crankshaft supports for allowing a pair of crankshafts to be simultaneously loaded into the fixture or unloaded therefrom.

31. A method for machining holes in at least two crankshafts simultaneously with the holes being at various circumferential positions about a longitudinal and rotational axis of each of the respective crankshafts and at various oblique angles relative to the longitudinal and rotational axis of the crankshaft; the method comprising:

loading a pair of crankshafts into a rotatable fixture with the crankshafts disposed side-by-side and supporting opposite ends of the respective crankshafts;

rotating the fixture about an axis which is at right angles relative to a tool plunging axis to locate the axes of the crankshafts at an oblique angle to the tool plunging axis;

rotating the respective crankshafts while being supported by the fixture about their respective longitudinal axes to align hole locations with each of a pair of respective tool plunging axes;

plunging the tools along parallel tool plunging axes and machining first holes in the respective crankshafts with the holes being at an oblique angle to the longitudinal and rotational axes of the respective crankshaft, while supporting opposite ends of the respective crankshafts;

shifting the crankshafts relative to the plunging tools for machining additional holes in the respective crankshafts while supporting the opposite ends of the respective crankshafts;

machining second holes in the crankshafts with at least one of the respective holes in each of the crankshafts being at an oblique angle to the longitudinal and rotational axis of the crankshaft; and

unloading of the respectively machined crankshafts.

32. A method in accordance with claim 31 comprising:

rotating the respective crankshafts along a path of travel between a changing position at which crankshafts with the holes therein are unloaded and new crankshafts are loaded and a machining position at which the new crankshafts are facing the spindles for receiving a plunging tool.

33. A method in accordance with claim 31 comprising:

loading a pair of crankshafts into a side-by-side position between headstocks and tailstocks; and

holding opposite ends of the respective crankshafts between the headstocks and tailstocks.

34. A method in accordance with claim 31 comprising:

using drills as the plunging tools; and

aligning drill bushings with the respective plunging drills and moving the drill bushings over the drills.

35. A method in accordance with claim 34 comprising:

providing an automatic toolchanger at a position remote from a machine head for the drills; and

automatically changing drills on each of the machine heads.

36. A method of machining at least two crankshafts with tools that form oil holes at an oblique angle to a longitudinal axis of each of the respective crankshafts, the method comprising:

positioning a crankshaft support to a changing position to receive at least two crankshafts therein;

loading the crankshafts into the support with the crankshafts positioned side-by-side while at the changing position and supporting opposite ends of the respective crankshafts;

rotating the crankshafts in the support to present predetermined locations on the crankshafts to be machined;

shifting the tools and support relative to each other to a machining position with the crankshafts facing the oil hole drilling tools to present the respective crankshafts to the tools with the tools being at a predetermined oblique plunging angle to the longitudinal axes of the respective crankshafts;

plunging the tools into the respective crankshafts to machine oil holes at the predetermined locations and at the predetermined oblique plunging angle to the longitudinal axis of the respective crankshaft;

removing the tools from the holes formed in the crankshafts; and

rotating the support from the machining position to the changing position to position the crankshafts for removal from the fixture.

37. A method in accordance with claim 36 comprising;

a changing of the crankshafts at the changing positions comprises shifting the respective headstocks and tailstocks relative to one another to release both ends of the crankshafts;

removing two machined crankshafts; and

subsequently loading two crankshafts to be machined into position between the respective headstocks and tailstocks and shifting the respective headstocks and tailstocks relative to one another to support the opposite ends of the crankshafts.

38. A method in accordance with claim 36 wherein the relative shifting of the tools and support comprises rotating the support about an axis oriented normal to the direction of plunging of the tools.

39. A method in accordance with claim 38 wherein the axis the support is rotated about is a horizontal axis.

40. An apparatus for machining holes in at least two crankshafts simultaneously with some of the holes being at an oblique angle to the longitudinal axis of the respective crankshafts, comprising:

a machine base;

a machine head carried by the base;

at least two spindles on the machine head, each rotatable about a first plunging axis, and each arranged to drive a separate tool and to plunge the tool into the crankshaft;

a fixture mounted on the machine base and rotatable about a second axis to position the respective crankshafts to allow machining of holes at various oblique angles to the longitudinal axes of the respective crankshafts;

clamping devices on the fixture each including a chuck and a tailstock for holding opposite ends of the respective crankshaft and for rotating the respective crankshafts about their respective longitudinal axes;

a drive motor associated with the chucks and tailstocks to rotate the crankshafts about their longitudinal axes to locate an area on the peripheral surface of the crankshaft to receive a hole; and

a motor drive for rotating the respective chucks and tailstocks with the crankshafts being held at opposite ends between a machining position in which the crankshafts are facing the spindles for machining holes therein and a changing position for changing the crankshafts by unloading the machined pair of crankshafts and loading a pair of crankshafts for machining by the respective spindles.

41. An apparatus in accordance with claim 40 comprising:

a drill bushing positioning device associated with drill bushings for positioning the drill bushings on the respective tools.

42. An apparatus for machining holes in at least two crankshafts at various peripheral locations about each crankshaft and through the respective crankshafts at various oblique angles to their separate longitudinal and rotational axes, comprising:

a frame;

a fixture on the frame for supporting opposite ends of a crankshaft and a crankshaft and for rotational positioning of the crankshaft about the crankshaft's longitudinal axis;

a headstock and tailstock on the fixture for supporting opposite ends of the crankshafts and for turning the crankshaft in a first, angular direction about the crankshaft's longitudinal axis while the crankshaft is supported in the fixture to present different peripheral surface sections of the crankshaft;

a first machine head for carrying a tool and for moving the tool along a first vertical axis for positioning the tool vertically relative to the crankshaft and for moving the tool along a horizontal plunging axis which is normal to the first axis for presenting the tool to the crankshaft;

a slide carried by the frame and constructed and arranged to move relative to the fixture and machine head along a third axis substantially perpendicular to each of the first and second axis;

a drive relative to the fixture and the crankshaft carried thereon through a second angular rotation relative to the plunging axis to machine holes at various oblique angles to the longitudinal axis of the crankshaft, the holes being machined at various peripheral locations about the crankshaft;

a second machine head having a tool synchronously movable with the first machine head to machine two crankshafts simultaneously; and

a second headstock and tailstock or the fixture for supporting the second crankshaft side-by-side with the first crankshaft, the headstocks and tailstocks supporting crankshafts for the synchronous rotational positioning of the crankshafts about the crankshafts' longitudinal axes.

43. An apparatus in accordance with claim 42 comprising;

a drill bushing positioning device associated with drill bushings for positioning the drill bushings on the respective plunging tools; and

an automatic toolchanger associated with the tool heads for automatically changing the tools on each of the respective plunging tools.

44. A crankshaft machining apparatus comprising:

a crankshaft having spaced ends, a main elongate portion of a predetermined length extending between the ends axially along a longitudinal axis of the crankshaft, and radially extending portions offset from the main elongate portion;

a machine head including a tool that forms holes in the crankshaft;

carriage mounts for the machine head including slides that position the tool relative to the crankshaft for a machining operation including guiding the head and tools for movement along a plunging axis toward the crankshaft;

a fixture having opposite end portions and a turning axis generally centrally disposed between the fixture end portions, the fixture supporting the crankshaft for shifting about the turning axis to allow the tool to machine holes in the crankshaft extending obliquely to the longitudinal axis thereof;

opposing crankshaft end mounts supported by the opposite end portions of the fixture for receiving the ends of the crankshaft so that the crankshaft is supported at both ends thereof with the length of the main portion of the crankshaft spanning the turning axis, and extending to the opposite end portions of the fixture with the crankshaft ends received in the end mounts; and

a rotary drive associated with the end mounts that rotates the crankshaft about the longitudinal axis thereof for machining the oblique holes at various circumferential positions about the crankshaft.

45. The crankshaft machining apparatus of claim 44 wherein the carriage slides allow for movement of the machine head in a vertical y-axis direction and a horizontal fore and aft z-axis direction.

46. The crankshaft machining apparatus of claim 45 wherein the carriage slides allow for movement of the machine head in a horizontal lateral x-axis direction.

47. The crankshaft machining apparatus of claim 44 wherein the fixture includes two pairs of opposing crankshaft end mounts for receiving respective ends of two crankshafts, and the machine head includes a pair of tools to allow simultaneous machining of oblique holes in the crankshafts.

48. The crankshaft machining apparatus of claim 44 wherein the carriage mounts and the fixture cooperate to position the tool relative to the crankshaft so that at least one of the oblique holes formed in the crankshaft extends through both the crankshaft main axial portion and one of the radially extending offset portions of the crankshaft.

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : RE 37,794 E
DATED : July 16, 2002
INVENTOR(S) : James Egbert

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 11,
Line 18, change “vertical” to -- horizontal --.

Column 12,
Line 41, after “slide” delete “35”.

Column 13,
Lines 49-53, after “machine head.” delete the rest of paragraph.

Column 15,
Line 59, change “Pivots” to -- pivots --.

Column 16,
Lines 34-35, after “crankshafts” insert -- , -- (a comma).

Signed and Sealed this

Twenty-third Day of December, 2003

JAMES E. ROGAN
Director of the United States Patent and Trademark Office